

ANALYSIS
Of a COURSE of
LECTURES,
ON
MECHANICS, || HYDROSTATICS,
PNEUMATICS, || AND ASTRONOMY,

Read by

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A Short Analysis of my Lectures having been called for by several Persons who attended them, I have drawn up the following one, for the use of those who may want such a help to their memory.—But my intention being to make it as concise as possible, I beg leave to refer those who choose to have the Lectures at large, together with accurate Plates of the Apparatus on which they are read, to my two Books, printed for, and sold by Mr. MILLAR, Bookseller in the Strand, London.*

J. F.

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ANALYSIS

OF A

COURSE OF LECTURES.

LECTURE I.

On MECHANICS.

WHEN two bodies are suspended upon any machine or engine, so as to act against one another, if the engine be put into motion, and the perpendicular ascent of one body be to the perpendicular descent of the other in the inverse ratio of their weights, they will balance or support each other.

Upon this principle, the force, power, or advantage of any machine, whether simple or compound, is easily computed: for it is always as much as the velocity of the power applied to work the machine is greater than the velocity of the weight to be raised, or the resistance to be overcome: proper allowance being made for friction.

The *machines* whereby power is gained, are called *mechanical powers*. They are six in number, *viz.* the *lever*, the *wheel and axle*, the *pulley*, or rather system of pulleys, the *inclined plane*, the *wedge*, and the *screw*.—Of these, all sorts of mechanical engines do consist: and in treating of them, so as to settle their Theory, we consider them as mathematically exact and perfect, and moving without friction.

A *lever* is a bar, turning upon a prop or center of motion; and is used either to raise weights, or to overcome resistances.—There are three kinds of levers; and in each of them, the velocity of each point is directly as its distance from the prop.

A lever

A lever is said to be of the first kind, when the prop is between the weight and the power.—Here, the power and weight balance each other, when the power is in proportion to the weight, as the distance of the weight from the prop is to the distance of the power from it. Of this sort are our iron crows, scissars, pincers, snuffers, and the like.

A lever is said to be of the second kind, when the weight is between the prop and the power.—Here, the power and weight balance each other, when the power is in proportion to the weight, as the distance of the weight (or resistance) from the prop is to the distance of the power from it. Of this sort are doors turning on hinges, rudders of ships, oars, and such cutting knives as are fixed at the point.

A lever is said to be of the third kind, when the power is between the weight and the prop. In this, the power and weight balance each other, when the power is in proportion to the weight, as the distance of the weight from the prop is to the distance of the power from it. Of this sort are the bones of our legs and arms, and the wheels of clocks and watches.

The bended lever differs in nothing but its form from a lever of the first kind: its power is the same, and is applicable to that of a hammer drawing a nail.

In the *wheel and axle*, the velocity of the power is to the velocity of the weight, as the circumference of the wheel is to the circumference of the axle; and the advantage gained by this machine is directly in the same proportion: for the power and weight balance each other, when the power is in proportion to the weight, as the circumference of the axle is to the circumference of the wheel. This machine is the principal part in a common *crane*.

A *pulley*, that only turns on its axis, and does not rise with the weight, serves only to change the direction of the power; for it gives no mechanical advantage thereto.

When,

When, besides the upper pulleys which turn round in a fixed block, there is a block of pulleys moving equally with the weight; the velocity of the weight is to the velocity of the power, as 1 is to twice the number of pulleys in the moveable block: and the power and weight balance each other, when the power is in proportion to the weight, as 1 is to twice the number of pulleys in the moveable block.

A weight raised, or a resistance moved, by an *inclined plane*, moves only through a space equal to the height or thickness of that plane, in the time that the power drives the plane through a space equal to its whole length. Hence, the velocity of the power is in proportion to the velocity of the weight, as the length of the plane is to its thickness or height; and the power and weight balance each other, when the power is proportioned to the weight, as the thickness of the plane is to its length.—All edge-tools which are chamfered only on one side are inclined planes, as far as the chamfer goes from the edge.

A *wedge*, in the common form, is like two inclined planes joined together at their bases; and the thickness or height of these planes make the back of the wedge, to which the power is applied in cleaving of wood.

When two equal resistances act perpendicularly against opposite sides of the wedge, and a power acts perpendicularly against the back of the wedge, the velocity of the power is in proportion to the velocity of the resistance, on each side, as the length of the wedge is to half the thickness of its back: and the power balances the resistance of the wood, when the power is in proportion to the resistance, as half the thickness of the back of the wedge is to its whole length, if the sharp edge goes to the bottom of the cleft in the wood. But when the wood splits before

the wedge, as it generally does, the velocity of the resistance on each side is to the velocity of the power acting on the wedge, as half the thickness of the wedge is to the whole length of the cleft. And in this case, the power and resistance balance each other, when the power is to the resistance, as half the thickness of the wedge (when it is driven quite into the wood) is to the whole length of the cleft below the back of the wedge.

The *screw* may be considered as if it were an inclined plane wrapt round a cylinder; hence, the power must turn the cylinder quite round, in the time that the weight or resistance moves through a space equal to the distance between the spirals or threads of the screw. Therefore, the velocity of the power is in proportion to the velocity of the weight or resistance, as the circumference of a circle described by the power, in one turn of the screw, is to the distance between the spirals of the screw: and the power and resistance balance each other, when the former is to the latter, as the distance between the spirals is to the circumference of the circle described by the power.—This machine, besides the advantage proper to itself, has generally the benefit of the wheel and axle, on account of the handle or lever by which it is turned.

As the screw includes the inclined plane, and two equally inclined planes make the wedge, we have all the mechanical powers combined together in a common *jack*, if it be turned by the fly: for then, we have also the lever, the wheel and axle, and the pullies.—If this machine be made use of for raising a weight, by a power applied to the fly, the power will balance the weight, if it be in proportion to the weight, as the velocity of the weight is to the velocity of the fly. Now, considering how fast the fly moves with respect to the motion of the weight, it is evident that a crane, constructed in the manner of a common jack, would

be

be an engine of very great power. But then the time lost would also be very great. For in all engines, the time lost in working them is as the power gained by them. If machines could be made without friction, the least degree of power added to that which balances the weight would be sufficient to raise it.—In the lever, the friction is next to nothing: in the wheel and axle it is but small: in the pulleys it is very considerable; and in the inclined plane, wedge, and screw, it is very great.

Pyrometers are machines for measuring the expansion of metals by heat. They are made of various forms, which cannot be described here. By two levers of the third kind, moving an index by means of a thread round a pulley on the axis of the index, a pyrometer may be made in a very small compass, which will shew the expansion of metals to the 70,000th part of an inch.

LECTURE II.

On MECHANICS.

THE *center of gravity* of a body is a point, round which all the parts of the body balance each other: and the body is moved by its own weight in the same manner that it would be, if its whole weight acted in that point. Therefore, the weight of a body will cause it to fall, unless its center of gravity be supported.

If a perpendicular, let fall from the center of gravity, falls within the base, or ground on which the body is placed, the body will stand: otherwise not.

A *cylinder* is supported on an inclined plane, by a power which is in proportion to the weight of the cylinder, as the height or thickness of the plane is to the length of the plane. If the power be less, the cylinder will run down the plane; if greater, it will be drawn up.—Hence, when the weight of a loaded

cart or *waggon*, and the angle of a hill's height, are given; the power required to support the load may be found. And if that power be encreased, so as to overcome the friction of the wheels on their axles, and the resistance arising from the inactivity of matter, the load will be drawn up.

Thus supposing the side of the hill to be a smooth plane, and the angle of its height to be 7 degrees 10 minutes, the perpendicular height of the hill is, in that case, equal to the eighth part of the length of its side: and the power that supports the load thereon is equal to an eighth part of the weight of the load.

If the angle of height be 14 degrees 28 minutes, the height of the hill is equal to a fourth part of the length of its side: and a power equal to a fourth part of the load will support it.

If the angle of height be 22 degrees 2 minutes, the height of the hill is equal to three eighth parts of the length of its side: and a power equal to three eighths of the load will support it.

If the angle be 30 degrees 00 minutes, the height of the hill is equal to half the length of its side: and a power equal to half the weight of the load will support it on the hill.

If the angle be 38 degrees 41 minutes, the height of the hill is equal to five eighth parts of the length of the side: and a power equal to the five eighths of the weight of the load will support it.

If the angle be 48 degrees 35 minutes, the height of the hill is equal to three quarters of the length of its side: and a power equal to three quarters of the weight of the load will support it.

If the angle of height be 61 degrees 3 minutes, the height of the hill is equal to seven eighth parts of the length of its side: and a power equal to seven eighth parts of the weight of the load will support it.

All these cases are experimentally proved by the inclined plane; which shews, that the power or advantage of that plane is as its length to the height.

It is proved, by working models of two *waggon*s, one of which has *broad* wheels and the other *narrow*, that broad wheels are just as easily drawn on hard ground as narrow ones; and easier on sandy ground, because they sink not so deep into the earth.—It is also plain by experiment, that let the wheels be either broad or narrow, the waggon is much easier drawn on rough ground, when the heaviest part of the load is put over the axle of the hind wheels, than when it is put over the axle of the fore ones.

In *water-mills*, the velocity of the float-boards of the wheel ought to be equal to a third part of the velocity of the water where it turns the wheel: and the train should be such, that the grinding-stone may make about 60 revolutions in a minute.

The number of rounds, or upright staves in the trundle, should be no aliquot part of the number of cogs in the wheel that turns the trundle: for then, each cog will fall upon a different round from what it did last before; and by that means they will all wear more equally, than if it took the same round in each revolution.

The *engine* by which the *piles* were driven at Westminster-Bridge was so contrived, that whilst the horses that turned it went constantly round, a weight was drawn up by it to a great height, then let fall freely on the top of the pile, and was immediately followed by a pair of tongs which took hold of the weight and drew it up again. A large fly regulated the motion, and acted against the horses, to keep them from falling forward when the weight dropt. The tongs were nearly counterpoised by another weight, whose line or rope wound round a spiral fusee, so as to cause the tongs to fall with a moderate and uniform velocity.

LECTURE III.

ON HYDROSTATICS.

FLUIDS press equally in all manner of directions, as is shewn by their motions in four glass tubes, open at each end; one tube being quite straight, another bent directly upward at the lower end, a third bent sidewise to a right angle, and the fourth bent obliquely. All these being put in water near to their tops, the water rises in each of them to a level with the surface of that in which they are immersed.

If a piece of lead, whose upper side is flat, be put into an empty vessel; and a piece of wood, whose under side is flat, be put upon the lead, so as no water may get between; and the wood be held down till the vessel be filled with water, the wood will remain upon the lead at bottom: for it is then kept down both by its own weight, and the weight of the water above it; the upward pressure of the water being prevented, as none gets in between the lead and the wood.

If a wide tube, open at both ends, has a piece of lead held close to its lower end, by a string within the tube, so as no water can get between the lead and the tube; and then, if the whole be immersed in water, till the depth of the lead below the surface of the water in the vessel be almost twelve times the thickness of the lead, the string may then be let go; for the lead will not fall away from the tube, because the upward pressure of the water is greater than the weight of the lead; and no water gets above it to press it down.—But if the tube and lead be raised, till the depression of the lead below the surface of the water in the vessel be any thing less than $11\frac{1}{3}$ times the thickness of the lead, it will then fall off: which shews, that lead is $11\frac{1}{3}$ times as heavy as its bulk of water.

If

If quicksilver be poured into a wide tube, which is close at bottom, to the height of an inch or two; and one end of a small tube, which is open at both ends, be immersed in the quicksilver; if then the large tube be filled to any height with water round the small one, the weight of the water on the quicksilver will press it upward in the small tube, till its height in that tube be a fourteenth part of the height of the water around the tube. This shews that quicksilver is fourteen times as heavy as water.

If a tube open at both ends has a bladder tied over one end, so as the bladder may be flaccid, and then some water be poured into the tube, it will press the bladder downward, and make it concave below the tube. But if that end be immersed in a vessel of water, till the surface of the water within the tube be even with the surface of the water in the vessel without it, the bladder will then be flattish, as if it were not pressed at all, because it is equally pressed on both sides.—If it be plunged deeper, it will be pressed upward, so as to be convex within the tube: if it be raised higher, it will be more pressed downward than upward, and be concave below the tube. And this will hold equally, whatever the size of the vessel be, in which the tube is immersed: which shews, that the pressure of fluids is in proportion to their perpendicular height, without any regard to their quantity.

If a small tube be joined to a very large one, and the whole be bent in the middle, so as the two parts may be either parallel, or make any angle; water may be poured into either tube, and it will rise just as high in the other, and settle with surfaces parallel to the horizon, when you leave off pouring; even though one tube should contain a thousand or ten thousand times as much as the other does.—This also shews, that fluids press in proportion to their perpendicular heights, without any regard to their quantities; and that water in pipes will ascend to the level of the spring, from whence it came.

If

If an empty phial, that is made heavy enough to sink in water, be corked and suspended at one end of a balance, and then immersed in water, and counterpoised by weights in a scale hung to the other end of the beam; upon pulling out the cork, and so letting water get in to fill the phial, it will immediately descend, and will then require as much weight put into the scale to counterbalance it again, as will weigh all the water in it, up to the neck, when taken out and weighed against this additional weight: which shews, that fluids weigh just as much in their own element as out of it.

If a small tube about two feet long, and open at both ends, has one end bent to a right angle, and the open neck of a large bladder be tied round that end; if then the bladder be put into a box, and have a board laid upon it with twenty-five or thirty pound weight of lead upon the board; and then the tube be held upright, and water be poured into it, the water will run into the bladder, and raise all the weight: and by the time that the water stands about eighteen or twenty inches high in the tube, it will support the weight; though the bore of the tube should be so small, as not to hold an ounce of water.

If a glass, with a piece of light wood in it, be filled up to the brim with water, and then weighed in a balance, with the wood floating in the water; if then the wood be taken out, and the glass filled up again to the brim with water, it will be just as heavy as when the wood was in it: which proves, that a quantity of water equal in bulk to the immersed part of the wood is equal in weight to the whole of the wood; and consequently, that the quantity of water displaced by a ship is equal to the weight of the ship and her whole cargo.

The pressure of a fluid, upon the bottoms of all vessels whatever, is proportional to their bases and

perpendicular heights, without any regard to the quantities they contain.—This is shewn by two vessels of equal heights and bases, but of very different capacities, their bottoms being held up by equal forces; for, at whatever height the water is in one vessel when it presses off the bottom, it does the like when poured in to the same height in the other.

A *siphon* will not run, unless the perpendicular height of the column of fluid in the outer leg be greater than the perpendicular height of the column in the inner leg above the surface of the fluid in the vessel in which that leg is partly immersed.

By the *Tantalus cup*, and *Fountain at command*, the cause of intermitting springs is explained.

L E C T U R E IV.

On SPECIFIC GRAVITIES, and HYDRAULIC ENGINES.

A Body heavier than its bulk of a fluid will sink therein; if lighter, it will swim: if of equal weight, it will rest any where between the top and bottom of the fluid.

If a solid body, heavier than its bulk of a fluid, be immersed and suspended therein, it will lose as much of its weight as its bulk of the fluid weighs: but the weight lost by the solid is gained by the fluid, as is proved by experiment. Hence, all equal bodies, immersed and suspended in a fluid, lose equal weights therein: and unequal bodies lose weights proportional to their bulks.

If the weight of a body in air be divided by what it loses in a fluid, the quotient will shew how much heavier it is than its bulk of that fluid; or its specific gravity.

By this trial, pure gold is found to be 19.637 times as heavy as its bulk of water: Guinea gold

17.793 times as heavy : quicksilver 14.000 times lead 11.325 times : standard silver 10.535 : copper 9.000 : plate brass 8.000 : steel 7.852 : iron 7.645 and block tin 7.321 :—A cubic foot of common water weighs 1000 avoirdupoise ounces ; and if the decimal point be taken away from the above numbers, and they reckoned to be whole, they will shew how many ounces avoirdupoise are contained in a cubic foot of each of the above bodies.—Thus, a cubic foot of pure gold weighs 19637 ounces ; a cubic foot of Guinea gold 17793 ; a cubic foot of quicksilver 14000 ; and so on.

A cubic inch of brass loses $253\frac{1}{3}$ grains of its aerial weight in water ; in proof spirits it loses 235 grains. Hence, a cubic inch of water weighs 253 grains, and a cubic inch of proof spirits 235.

The specific gravities of pure spirits, proof spirits and water, are as 840, 923, and 1000.

In a *common pump*, as the piston is raised, above what is called the sucking valve, the water rises by the pressure of the atmosphere to the height of 33 feet, and no higher. Therefore, the bucket must go down to within 33 feet of the surface of the water in the well ; otherwise, the water will never get above the bucket, and the pump will not work.

This shews, that a column of water 33 feet high is just as heavy as a column of air of the same thickness with that of the water, and reaching from the earth's surface to the top of the atmosphere.

But at any distance less than 33 feet from the surface of the well, the water will rise above the bucket ; and may then be lifted to any height whatever, by applying a sufficient degree of power to the handle.

In a *forcing pump*, the water rises above the sucking valve, by the pressure of the atmosphere, as in the common pump. But instead of a bucket, there is a solid plunger that fits the pump-bore, so as neither

water

water nor air can get between. As the plunger is raised, it lifts up all the air above it, and the atmosphere forceth the water up into the pump-barrel, through the sucking valve, which being raised by the upward pressure of the water, falls down by its own weight when the plunger is raised as far as it can go by means of the handle ; for then, the water being at rest below the plunger, gives the valve liberty to fall ; and so the valve hinders the water from being pushed back the same way again by the descending plunger : but the descent forceth the water through another pipe, which opens into the pump-barrel above the sucking valve ; and may be forced to any given height in that pipe, or in a jet from it, according to the degree of power applied to the handle. An air-vessel is fixed to this pipe, by means of which, as the air is condensed within it, the water flows out in a regular continued stream.—The common engine for extinguishing fire consists of two forcing pumps, with their air-vessels.

On this principle, engines are made for raising water above the level of rivers or springs, to gentlemen's seats ; and are sometimes worked by water, sometimes by horses. If such an engine has a triple crank for working three pumps, all of them throwing the water into one common conduit pipe, there will be no occasion for an air-vessel ; because there will always be one or other of the plungers going downward, which will force the water out in a regular stream.

LECTURE V.

On PNEUMATICS.

THE structure of the principal parts of the *air-pump* is so much like that of the common water-pump, that whoever understands the one, will be at no loss to understand the other. The

chief use of this engine is to exhaust the air out of glass vessels, generally called *receivers*.

If a small receiver, open at both ends, be placed over the hole in the pump plate, and a person claps the palm of his hand on the top of the receiver, whilst another person exhausts the air out of the receiver, his hand will be held down so fast by the pressure of the atmosphere, that he cannot pull it off until the air be let into the receiver again.

If a guinea and the down of a feather be hung within the top of a tall receiver, and let fall after the air is exhausted out of it, they will both fall at the same instant on the pump plate whereon the receiver stands.

If a wet bladder be tied over the top of an open receiver, then set to dry, so as to be tight like a drum; and the receiver be then put upon the pump plate, and the air exhausted out of it, the bladder will be broke by the weight of the atmosphere.

If the neck of a hollow glass bubble be immersed in a phial of water, and covered with a close receiver, and then the air be exhausted out of it; upon letting the air in again, its pressure on the water in the phial will force the water up into the bubble, so as almost to fill it.

If a bell be covered with a close receiver, and the air be exhausted out of it, the striking of the clapper against the sides of the bell will not be heard.

If a pump be placed in water, under a receiver, and the air be exhausted, no water can be raised by working the piston, until the air be let in again: which shews, that the water rises by the pressure of the air; and not by any such thing as suction in the pump.

If a small receiver be placed on the pump plate, at some distance from the hole, and covered with a
large

large receiver over the hole ; and then, if the air be exhausted out of both receivers, the small one will continue loose on the plate, and the large one will be prest down upon it. But, upon letting the air into the big receiver, it will be released, and the small one will be prest down : which shews, that the receivers are held down by pressure, and not by suction.

If a vessel be exhausted of air, and then balanced in a pair of scales ; upon letting the air into it again, it will preponderate, and be found to weigh heavier, by about 16 grains, for every quart it holds.

If a hole be made in the bottom of a cup, and have a bit of dry hasel or willow branch fixed into it, and the other end of the branch be fixed into a hole in the top of a receiver ; if quicksilver be poured into the cup, and the air be exhausted out of the receiver below it, the quicksilver will be forced through the pores of the branch, by the weight of the incumbent air ; and will fall, like a shower, into the receiver.

If a pipe be fixed into a plate which covers the open end of a tall receiver, and the air be exhausted ; if then the lower end of the pipe be immersed into a bason of water, the pressure of the air will force the water upward, so as to make a fountain in the exhausted receiver.

If the air be exhausted out of two hemispherical brass cups, joined together only by a piece of wet leather put between them ; if the diameter of each cup be $5\frac{1}{2}$ inches, it will require a force equal to 360 pounds to separate them ; so strongly are they held together by the pressure of the outward air.

If a tube about 31 or 32 inches long, and open at one end, be filled with quicksilver, and the open end be immersed in a jar in which there is some quicksilver, the quicksilver will sink in the

tube to the height at which it then stands in the barometer. If this jar and tube be placed on the pump plate, and covered with a tall receiver, close at top, and then the air be exhausted out of the receiver, all the quicksilver will descend out of the tube into the jar: but, upon admitting the air again into the receiver, it will press on the quicksilver in the jar so, as to drive it up into the tube, and support it at the same height therein as it stands in the barometer: which shews, that the quicksilver in the barometer is kept up solely by the weight of the air.

LECTURE VI.

On PNEUMATICS.

IF a leaden weight of three or four pounds be fixed to the end of a syringe, and the piston be drawn up, the lead and syringe will be forcibly pushed up on the piston, by the upward pressure of the air.

If a large cork be exactly counterbalanced in air by a piece of lead, and then covered with a receiver; upon exhausting the air, the cork will preponderate, and shew itself to be heavier than the lead.

If a candle be set on the pump plate, and covered with a tall receiver that holds a gallon, the candle will burn for one minute and no longer: which shews, that a gallon of fresh air is requisite every minute to feed the flame of a candle. When the flame goes out, the smoke will continue to ascend in the receiver; but, on exhausting the air out of the receiver, the smoke will fall down to the bottom of it on the pump plate. This shews, that smoke is not devoid of weight, and that it ascends in air, only because it is lighter than air; as wood ascends in water for the like reason.

If a little air be tied up in a bladder, and the bladder be covered with a close receiver, upon exhausting the air out of the receiver, the air confined in the bladder will expand so, as to make the bladder appear full blown: but, upon admitting air again into the receiver, the bladder will be prest into its former shrivelled state.

If the same bladder be put into a box, and have 16 or 20 pound weight of lead put upon it, and then covered with a receiver; upon exhausting the air out of the receiver, the air confined in the bladder will raise up the leaden weights by the force of its spring.

Most sorts of animals will die in the greatest agonies in an exhausted receiver.

If a tube, open at both ends, has one end immersed into a jar about a third part full of quicksilver, and the tube be cemented (or screwed) into the jar, to confine the air therein that lies above the quicksilver, and the tube and jar be covered with a tall receiver; on exhausting the receiver, the air will come out of the tube by means of its spring, and the spring of the air which is confined in the jar will force the quicksilver up into the tube, as high as it was raised in a former experiment by the weight of the air: which proves, that the spring of the air is equal to its pressure or weight.

If a tall receiver be exhausted of air, and joined by a pipe to a vessel about half full of water, so as to be quite air-tight, the spring of the air that lies above the water in the vessel will force the water up into the receiver, and make a fountain therein.

If a shrivelled apple be put under a receiver, and the receiver be exhausted of air; the air confined in the apple will plump it out, and make it look quite fresh: but on letting the air into the receiver again, its weight will reduce the apple to its former shrivelled state.

If a fresh apple be pricked all over with a bodkin, and put under a receiver; upon exhausting the air out of the receiver, the air in the apple will force the juice out through the holes made by the bodkin; and make the apple look as if it were roasting by a fire.

If a little of the shell be cut off from the smallest end of a fresh egg, and the egg be put under a receiver; on exhausting the receiver, the bubble of air confined in the biggest end, between the film and shell, will expand itself so by the force of its spring, as to drive [out] the contents of the egg into the exhausted receiver.

If a glass of warm beer be put under a receiver, and the receiver be exhausted, the beer will shew all the appearance of boiling, as the air comes out of it by the force of its spring.

If about a cubic inch of dry wainscot be put into a glass of warm water, and covered with a receiver; on exhausting the air out of the receiver, the water will seem to boil; and a long time after it has done bubbling, the air will continue to come out of the wood in large and innumerable bubbles, which striking against the sides of the glass, and rebounding against the wood, will cause it to dance to and from in the water.

If a receiver be exhausted of air, and then the air be let into it through the flame of a candle, held to the end of a pipe which opens into the receiver through a brass cover, the receiver will be filled with burnt air. If then the cover be taken off, and an animal be put into the receiver, it will die; or if a lighted candle be put into the receiver, it will go out immediately.

LECTURE VII.

On the USE of the GLOBES.

WHEN the earth's shadow falls upon the moon, it is bounded by a circular line, whatever side of the earth be then turned toward the moon.—This proves the earth to be a spherical body, and not an extended plane. Its circumference is found (by measuring the length of some degrees on its surface) to be $25,038\frac{1}{2}$ English miles; and consequently its diameter is 7970.

All terrestrial bodies are attracted towards the earth's center; and, therefore, nobody can fall from any part of its surface any other way than toward its center.—Hence, people stands equally firm on all sides of the earth.

The four principal continents are, Europe, Asia, Africa, and America.

The principal Oceans are, the Northern Ocean, the Atlantic Ocean, the Ethiopic Ocean, the Indian Ocean, the Pacific Ocean, the Southern Ocean.

According to measurement from the best maps, the seas and unknown parts contain 160,566,276 square miles; the inhabited parts 38,990,569; Europe 4,456,065; Asia 10,768,823; Africa 9,654,807; America 14,110,874. In all, 199,556,845; which is the number of square miles on the whole surface of our globe.

When a spherical ball has the different countries and kingdoms delineated upon it, and the rivers and towns therein properly marked, it is a representation of the earth: for the hills take off no more in comparison from the roundness of the earth, than grains of dust do from the roundness of a common globe.

When a hollow spherical ball of glass has the stars properly marked on its inside, with the sun, moon, and

and planets, it is a representation of the visible heavens, to an eye supposed to be placed in its center.—But because it would be impossible to have these in a complete hollow ball of glass, unless it were made up of two hemispheres joined together, the stars are laid down on the surface of an opaque globe. The sun and planets are continually changing their places, and therefore they cannot be marked any other way than by a pencil or chalk occasionally.

The chief problems which may be solved by a terrestrial globe, properly fitted up, are as follow.

1. To find the latitude and longitude of any given place.
2. The latitude and longitude being given, to find the place.
3. To find the difference of latitude, or difference of longitude, between any two given places.
4. A place being given, to find all those places which have the same latitude or longitude with it.
5. To find the *antæci*, *periæci*, and *antipodes* of any given place.
6. To find the distance between any two given places.
7. A place being given, and its true distance from any other place, to find all the other places which are at the same distance from the given place.
8. The hour of the day at any place being given, to find all those places where it is noon at that time.
9. The hour at any place being given, to find what o'clock it then is at any other place.
10. To find the sun's place in the ecliptic, and his declination.
11. The day of the month being given, to find all those places over which the sun will pass vertically on that day.

12. A place being given in the torrid zone, to find those two days of the year on which the sun shall be vertical to that place.

13. To find all those places of the north frigid zone where the sun begins to shine constantly without setting on any given day, from the 21st of March to the 23^d of September.

14. To find to what place the sun is vertical at any given time.

15. The day and hour at any place being given, to find all those places where the sun is then rising, or setting, or on the meridian: consequently, all those places which are enlightened at that time, and those which are in the dark.

16. The day and hour of a lunar eclipse being given, to find all those places at which it will be visible.

17. To rectify the globe for the latitude, zenith, and sun's place.

18. The latitude of any place not exceeding $66\frac{1}{2}$ degrees being given, to find the time of sun-rising and sun-setting at that place.

19. The latitude of the place, and the day of the month, being given; to find when the morning twilight begins, and evening twilight ends.

20. To find on what day of the year the sun begins to shine constantly without setting, at any place of the north frigid zone: and how long he continues to do so.

21. To find in what latitude the sun shines constantly, without setting, for any length of time less than 182 of our days and nights.

22. To find on what point of the compass the sun rises, or sets, in any given latitude less than $66\frac{1}{2}$ degrees.

23. The latitude, the sun's place, and his altitude, being given; to find the hour of the day, and the sun's azimuth.

24. The latitude, the sun's place, and his azimuth, being given ; to find the hour of the day, and the sun's altitude.

25. The latitude, the sun's place, and the hour of the day, being given ; to find the sun's altitude, and his azimuth.

26. The latitude, the sun's place, and his altitude, being given ; to find the variation of the compass.

27. The latitude, the sun's altitude, and his azimuth, being given ; to find his place in the ecliptic, the day of the month, and the hour of the day ; though they had all been lost.

28. To find the length of the longest day, at any given place.

29. The length of the longest day, at any place being given ; to find in what climate that place is.

30. To find in what latitude the longest day is of any given length less than 24 hours.

31. The latitude, and day of the month, being given ; to find the hour of the day when the sun shines.

32. To explain the equation of time.

33. To explain the phenomena of the harvest-moon.

34. To explain the principles of dialing, and to construct a sun-dial on any plane, for any given latitude.

The chief problems which may be solved by the celestial globe are these that follow.

1. To find the right ascension and declination of the sun, or of any star.

2. To find the latitude and longitude of any star.

3. To represent the face of the heavens at any hour of the night.

4. To find the time, on any given day, when any star will rise, or be on the meridian, or set.

5. To

5. To find at what time of the year a given star will rise, or be upon the meridian, or set, at any given hour.

6. Divers ways of finding the hour of the night by the stars.

7. To find the place of the moon, or of any planet, on the globe; and the time of its rising, or southing, or setting.

8. To explain the precession of the equinoxes.

N. B. All problems relating to the sun may be solved either by the celestial or terrestrial globe. The method of solving them would enlarge this treatise much beyond the intended bulk: but it is to be found in Mr. *Harris's* book on the use of the Globes, sold by Mr. *Cole* at the *Orrery* in Fleet-street; or in my book of Lectures, sold by Mr. *Millar*, Bookseller in the Strand.

LECTURE VIII.

On the CENTRAL FORCES, and doctrine of the TIDES.

MATTER, being inert, can neither move nor stop of itself, as is shewn by a ball on the *whirling table*; which neither begins to move when the table moves, nor stops when the motion of the table is stopped.—Consequently, all motion is in its own nature perpetual. And yet, no perpetual motion can be made by art, because we can neither annihilate friction, nor quite take off the resistance of any medium.

Motion is rectilinear, when only one force or power acts upon the moving body. Therefore, when we see a body move in a curve of any kind whatever, we must conclude it is acted upon by two powers at least.

All bodies moving in orbits, have a tendency to fly off from their orbits, and move in right lines:

therefore, to keep them in their orbits, some active power must be constantly drawing them, or impelling them, toward the center of their orbits: as is evident by a pebble whirled round one's hand in a sling.

The planets are retained in their orbits by the power of gravity, and they are moved in their orbits by a projectile force impressed upon them at the beginning.

If the power of gravity alone acted on the planets, it would bring them down to the sun.—If the projectile force acted alone on the planets, it would carry them off in straight lines, which would be tangents to their orbits.

The sun and planets mutually attract each other, in proportion to their quantities of matter.—The sun's attraction is that which causes or constitutes the gravitation of the planets.

The center of gravity of any two revolving bodies is a point, round which they are in *æquilibrio*: its distance from their centers is inversely as their quantities of matter.

When one body moves round another, both of them must move round their common center of gravity, as is plainly proved by experiment. Hence, the largest body in the solar system could not remain immovable, if any other body moved round it.

The quantity of matter in the sun is much greater than in all the planets put together. Therefore, the common center of gravity between the sun and planets is much nearer to the sun than to any planet in the system.

The common center of gravity between the sun and all the planets is at rest: but the common center of gravity between any planet and its satellite is moveable, and describes the orbit in which the planet itself would move if it had no satellite.

The common center of gravity between the earth and moon is 6000 miles from the earth's center.— As the earth and moon move round their common center of gravity every month, the earth's center describes a circle of 12000 miles diameter in that time: and consequently, the earth is 12000 miles nearer the sun at the time of full moon, than at the time of new moon.

All parts of the earth have a tendency to fly off, in proportion to their distance from this common center of gravity: therefore the side of the earth which is at any time turned away from the moon has a greater centrifugal force, or tendency to fly off, than the earth's center has: and the earth's center has a greater centrifugal force, than that side of the earth which is turned towards the moon.

At the earth's center, the moon's attraction balances the centrifugal force: consequently, her attraction on the side next her is stronger than the centrifugal force of that side; and weaker than the centrifugal force of the side farthest from her. As the moon's attraction on the side of the earth next to her is greater than the centrifugal force of that side, her attraction causeth the tide to rise on that side.

As the centrifugal force of the side of the earth farthest from the moon is greater than the moon's attraction, the centrifugal force causeth the tide to rise on that side.

The tides rise equally high, or nearly so, at the same time, on both sides of the earth; because the centrifugal force of the side that is farthest from the moon overbalances her attraction very nearly as much, as her attraction on the side next her overbalances the centrifugal force of that side.

A double velocity, in the same orbit, balances a quadruple power of attraction at the center of that orbit, as is manifest by experiment.—Therefore, if the velocity of any planet were twice as great as it

now is, the sun's attraction would need to be four times as great, in order to retain the planet in its orbit.

The squares of the planets periods round the sun are found by observation to be as the cubes of their distances from the sun.—If this be represented on the whirling table, it appears, that the powers at the center requisite to keep the planets in their orbits, are inverſly as the ſquares of their diſtances from the center of their orbits: which proves, that the ſun's attraction diminifhes in proportion as the ſquares of the diſtances from him increaſe: that is, at a double diſtance, his attraction is four times leſs; at a triple diſtance, nine times leſs; at a quadruple diſtance, ſixteen times leſs; and ſo on.

The motions of the comets prove the *Carteſian* doctrine of vertexes to be abſurd. This is alſo proved by an experiment on the whirling table, made by mercury and water in one tube, and water and cork in another.

The earth is of a ſpheroidal figure, as is proved by the French obſervations; its equatoreal diameter being longer than its axis.—This demonſtrates that the earth turns on its axis: for, if it did not, the water would leave the equatoreal regions, and overflow the polar.—The whirling ſphere proves, that this figure of the earth ariſes from its motion on its axis.

LECTURE IX.

On ASTRONOMY.

NO ſcience is comparable to this, in giving us noble ideas of the Deity and his works; and drawing us near to him. The earth is at leaſt 160 millions of miles nearer ſome of the ſtars at one time of the year than another: and yet, the apparent magnitudes of theſe ſtars, and their angular diſtances

distances from each other, is still the same: which proves, that the distance of the stars from us is exceeding great.

At the distance of any star, all the planets in our system would disappear: and the sun would appear no bigger than a common star does to us. Consequently, each star may be a sun to a system of planetary worlds, which our best telescopes cannot possibly discover.

The stars are vastly too remote from the sun, to be enlightened by it, so as to reflect light enough to make them visible. Hence it is plain, that they shine by their own native and unborrowed lustre.

Those of the first magnitude cannot be less than the sun; otherwise they could not appear so large to us as they do.—Since they are so large, and shine by their own light, they are suns.

It is probable that all the rest are as large, and only appear to be of different magnitudes, by reason of their different distances.

The number of systems which would stand around our solar system, and next to it, is much less than the number of those which might stand next around them.—And so on to infinity. But the stars of the first magnitude are much fewer in number than those of the second: those of the second much fewer than those of the third: and so on.

This circumstance makes it highly probable, that the stars of the first magnitude are suns to those systems of planets next around our system: those of the second magnitude, suns to those systems next beyond our neighbouring systems: and so on, to the stars of the sixth magnitude, which are the smallest that common eyes can perceive.

But by means of the telescope, thousands of stars are discovered, which are quite invisible to the bare eye. Those are certainly of no manner of use to us; but we cannot therefore conclude, that they
are

are useless ; and consequently we infer, that they are suns to particular systems of worlds.

Our earth, if seen from the sun, would appear no bigger than a point ; as is evident from the smallness of the sun's parallax.—It is a planet only of the third magnitude, for it is much less than *Saturn*, and *Saturn* is considerably less than *Jupiter*.

The solar system consists of the sun, six primary planets, ten secondary planets or moons, and the comets.

The six primary planets are *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*.—The *Earth* has one moon, *Jupiter* has four, and *Saturn* five.

All the planets move round the sun from west, by south, to east ; in orbits which are nearly circular, and but little inclined to each other.—The comets move in all sorts of directions, in orbits which are very long ellipses, much inclined to one another, and to the orbits of all the planets. The tails of the comets are only thin vapours : for, if they were flame, no star could be seen through them.

The time in which any planet goes round the sun, is the length of its year ; and the time in which it turns round its axis, is the length of its day and night taken together.

Mercury goes round the sun in 87 days 23 hours : its diameter is 2600 English miles, its distance from the sun is 32,000,000 of miles, and its hourly motion in its orbit is 95,000 miles. The time of its diurnal rotation, or length of its days and nights, is unknown.

Venus goes round the sun in 224 days 17 hours : its diameter is 7900 miles, its distance from the sun is 59,000,000 of miles, its hourly motion in its orbit is 69,000 miles, and it turns round its axis in 24 days 8 hours of our time.

The *Earth* goes round the sun in 365 days 5 hours 49 minutes : its diameter is 7970 miles, its distance

distance from the sun is 81,000,000 of miles, its hourly motion in its orbit is 58,000 miles, and it turns round its axis in 24 hours.

The *Moon* goes round the earth, from change to change, in 29 days 12 hours 44 minutes; and turns round her axis in the same time. Her different phases prove that she shines by reflecting the light of the sun, and not by any light of her own. Her diameter is 2170 miles, and her distance from the earth is 240,000. In respect of the earth she moves 2290 miles each hour in her orbit.

Mars goes round the sun in 686 days 23 hours: its diameter is 4444 miles, its distance from the sun is 123,000,000 of miles, its hourly motion in its orbit is 47,000 miles, and it turns round its axis in 24 hours 40 minutes.

Jupiter goes round the sun in 4332 days 12 hours: its diameter is 81,000 miles, its distance from the sun is 424,000,000 of miles, its hourly motion in its orbit is 25,000 miles, and it turns round its axis in 9 hours 56 minutes.

This planet has four moons moving round it, at different distances. Its first or nearest moon goes round it in 1 day 18 hours 36 minutes, the second in 3 days 13 hours 15 minutes, the third in 7 days 3 hours 59 minutes, and the fourth in 16 days 18 hours 30 minutes.

Saturn goes round the sun in 10,759 days 7 hours: its diameter is 67,000 miles, its distance from the sun is 777,000,000 of miles, and its hourly motion in its orbit is 18,000 miles. The time of its rotation on its axis is unknown.

This planet has five moons, the nearest of which goes round it in 1 day 21 hours 19 minutes, the second in 2 days 17 hours 40 minutes, the third in 4 days 12 hours 25 minutes, the fourth in 15 days 22 hours 41 minutes, and the fifth in 79 days 7 hours 48 minutes.

If a body, projected from the sun, should continue to fly at the rate of 480 miles every hour (which is about the swiftness of a cannon-ball) it would reach the orbit of Mercury in 7 years 221 days; of Venus in 14 years 8 days; of the Earth in 19 years 91 days; of Mars in 29 years 85 days; of Jupiter in 100 years 280 days; of Saturn in 184 years 240 days; and to the nearest of the stars in about 8 millions of years.

The sun's light diminishes in proportion as the squares of the distances from him increase.—Mercury is seven times as much enlightened as the Earth is: Venus twice as much; Mars has little more than a fourth part of so much light as the Earth has: Jupiter has only a twenty-eighth part, and Saturn a ninetieth part.

The sun's diameter is 763,000 miles. If we suppose it to be divided into 10,000 equal parts, Mercury's diameter will contain $34\frac{1}{3}$ of such parts; Venus's diameter $103\frac{4}{7}$; the Earth's $104\frac{3}{7}$; the Moon's $28\frac{1}{2}$, Mars's $58\frac{1}{8}$; Jupiter's $1061\frac{2}{3}$, and Saturn's $878\frac{1}{9}$.

Now, let us suppose that an *Orrery* is intended to be made, in which the sun and planets shall be represented in their proportional magnitudes, and the planets placed at their proper distances from the sun, in proportion to their magnitudes; as in the heavens: the sun's diameter in the *Orrery* being 12 inches.

In this case, the diameter of Mercury would be $\frac{42}{1000}$ parts of an inch; the diameter of Venus $\frac{124}{1000}$ parts; the diameter of the Earth $\frac{125}{1000}$ parts (which is equal to the eighth part) of an inch; the Moon's diameter $\frac{34}{1000}$ parts; Mars's diameter $\frac{70}{1000}$ parts of an inch; Jupiter's diameter one inch and $\frac{274}{1000}$ parts; and Saturn's diameter, exclusive of his ring, one inch and $\frac{54}{1000}$ parts.

Then,

Then, the true proportional distances of these planets from the sun would be as follows: Mercury's distance 43 feet 1 inch; Venus's distance 77 feet 2 inches; the Earth's distance 105 feet 10 inches; the Moon's distance from the Earth $3\frac{3}{16}$ inches; Mars's distance from the sun 161 feet 5 inches; Jupiter's distance 555 feet 9 inches; and Saturn's distance 1018 feet 7 inches, or 339 yards 1 foot 7 inches.—So that the circumference of Saturn's orbit would be 2130 yards; or a mile and almost a quarter.

Consequently, there is no such thing as having the sun and planets in their relative magnitudes, and at their proportional distances, in an *Orrery*; even though the earth should be no more than the eighth part of an inch in diameter.

LECTURE X.

On ASTRONOMY.

THE axis of any planet is a physical line, round which the planet turns: and the extremities of that line are its poles.

The earth's motion on its axis is the cause of day and night: for its turning round every 24 hours produces the same effect, as if the sun moved round it in that time.

The earth's axis inclines $23\frac{1}{2}$ degrees from a perpendicular to the ecliptic, or orbit in which the earth moves round the sun. Therefore, the earth's poles can never incline more than $23\frac{1}{2}$ degrees toward or from the sun.

The obliquity of the earth's axis, and its constant parallelism during its annual course round the sun, are the causes of the different seasons, and different lengths of days and nights.

The north pole of the earth's axis inclines more or less toward the sun, from the vernal equinox to

the autumnal; and more or less from the sun, from the autumnal equinox to the vernal.—In the former case, it is the summer half year in the northern hemisphere of the earth; in the latter case, the winter half year: and the contrary in the southern hemisphere of the earth. For, when the north pole inclines toward the sun, the south pole declines from him, and *vice versa*.

In the northern hemisphere, the vernal equinox (or equal day and night in the spring) is on the 20th of March; and the autumnal equinox (or equal day and night in autumn) is on the 23d of September. In the southern hemisphere, the contrary.

The earth goes round the sun once a year in the plane of the ecliptic: and therefore, as seen from the earth, the sun appears to go round the ecliptic in the same time. For, in whatever place of the ecliptic the earth is, at any time, as seen from the sun, the sun, as seen from the earth, will seem to be in the opposite part of the ecliptic.

The equator is a great circle, all round the earth: it divides the earth into two equal parts, called the northern and the southern hemispheres. The north pole is the middle point of the northern hemisphere, the south pole the middle point of the southern.—The equinoctial circle in the heaven is directly over the earth's equator, and divides the heaven into two equal parts, called its northern and southern hemispheres. The poles of the heaven are directly over the poles of the earth.

At the equinoxes, the earth's axis inclines neither toward the sun, nor from him: at the solstices (which are the middle days of summer and winter) it inclines $23\frac{1}{2}$ degrees toward or from the sun, according as it is summer or winter in the given hemisphere.

At the equinoxes, the sun is in the equator: at the solstices he is $23\frac{1}{2}$ degrees from the equator.

When the sun is in the equator, he enlightens the earth from pole to pole. At all other times, he shines

as many degrees round the pole which is turned toward him, as he is distant from the equator toward that pole. And just so many degrees is the opposite pole involved in darkness.

The sun is on the north side of the equator from the 20th of March to the 23d of September: and on the south side of the equator from the 23d of September to the 20th of March.—By these two propositions it is plain, that at the poles there is but one day and one night in the whole year.

The northern tropic is a circle $23\frac{1}{2}$ degrees on the north side of the equator; the southern tropic is a circle $23\frac{1}{2}$ degrees on the south side. These are the limits of the sun's greatest north and south declinations.

The polar circles are $23\frac{1}{2}$ degrees distant from the poles, all around. When the sun is in the northern tropic, the whole space within the north polar circle is enlightened, and all within the south polar circle is in darkness: the contrary, when the sun is in the southern tropic.—All these things are plainly shewn by the *Orrery*.

The meridian of any given place is a semicircle passing through that place, cutting the equator at right angles, and terminating in the poles.

The earth's circumference is 360 degrees; and as the earth turns round its axis from the sun to the sun again, in 24 hours, each meridian revolves 15 degrees in an hour; for 24 times 15 is 360.

Every place, whose meridian is eastward 15, 30, 45, 60, or 75 degrees (and so on, increasing by 15) from the meridian of any given place, has noon, and every other hour, one, two, three, four, or five hours (and so on in proportion) sooner than the like hour is at the given place: if westward, so much later.

The longitude of any place is the number of degrees intercepted between its meridian and the meridian of any given place from which the longitude is reckoned:

ked: and is east or west, according as that place is east or west from the meridian of the given place.

The eclipses of Jupiter's satellites afford a method of finding the longitude, according to the observed times of their happening, as seen from different places of the earth.—Thus, supposing an eclipse of any satellite to happen at six in the morning at London; and that it was seen at another place at four in the morning: the difference of time is two hours, which answers to 30 degrees. Consequently, the meridian of the place where the eclipse was seen at four in the morning is 30 degrees west from the meridian of London, where the same eclipse was seen at six in the morning.

The same eclipses shew, that the motion of light is not instantaneous, but that it takes about 16 minutes to travel through a space equal to the diameter of the earth's orbit. For, when Jupiter is nearly in conjunction with the sun (that is when the sun is between the earth and Jupiter) these eclipses happen 16 minutes later than when Jupiter is in opposition to the sun, which is, when the earth is between the sun and Jupiter. In the latter case, the earth is nearer to Jupiter by the whole diameter of its orbit (which is 162 millions of miles) than in the former. Therefore, as the sun is nearly in the center of the earth's orbit, and his mean distance from the earth is 81 millions of miles; and since light moves through a space equal to the whole diameter of the earth's orbit in 16 minutes, it moves from the sun to the earth in eight minutes; which is almost as far as a cannon-ball would go in 20 years.—Hence it appears, that light moves at the rate of 592,180,000 miles in an hour; 9,869,666 miles in a minute; and 164,494 miles in a second; which is 10,210 times as fast as the earth moves in its annual orbit.

LECTURE XI.

On ASTRONOMY.

THE moon turns round her axis in the same time that she goes round the earth in her orbit, and therefore, she always keeps the same side toward the earth.

Her periodical revolution, or time of going round from any point of her orbit to the same point again, is 27 days 7 hours 43 minutes.

Her synodical revolution, or time from change to change, is 29 days 12 hours 44 minutes; which is the length of her day and night taken together: for, as seen from the sun, she turns only once round her axis in that time.

If the earth had no progressive (or annual) motion round the sun, the same point of the moon's orbit would always keep between the earth and the sun: and then there would be no difference between her periodical and synodical revolution; for she would always change in the same point of her orbit.

But, as the earth is in motion round the sun, and the signs of the moon's orbit always keep parallel to the like signs of the fixt ecliptic; a different part of the moon's orbit will be every day between the earth and the sun from that which was so on the day before: and, therefore, the moon must move as many degrees more than round her orbit, between any change and the next following, as the earth has advanced in the ecliptic during that time; which is $29\frac{1}{16}$ degrees.

As the moon goes quite round her orbit in 27 days 7 hours 43 minutes, and the earth goes round the sun but once a year, the earth's axis has all the different positions to the moon in the time she goes round her orbit, that it has to the sun in one year.

The

The moon shines only by reflecting the sun's light; for if she was a luminous body, she would always appear round, as the sun does.

A luminous body can enlighten only one half of a dark globe at once: therefore, at any given moment, the sun can enlighten only one half of the moon.

When the moon is between the earth and the sun, she disappears, because her unenlightened side is then toward the earth. When she is opposite to the sun, she appears full, because her illuminated side is then toward the earth. When she is 90 degrees, or a quarter of a circle, distant from the sun, she appears half full; because one half of her enlightened side is then toward the earth.

The earth and moon are mutually moons to each other: but the earth gives 13 times as much light to the moon, as the moon gives to the earth; for the earth's surface is 13 times as big as the moon's.

In considerable latitudes, the different parts of the ecliptic rise at very different angles with the horizon.—In northern latitudes, the signs *pisces* and *aries* rise with the smallest angles, *virgo* and *libra* with the greatest. Therefore,

When the moon is in *pisces* and *aries*, she rises nearly at the same hour for six or seven days together: but when she is in *virgo* and *libra*, she rises so much later every day, as to differ eight hours in six or seven days.

In our winter, the moon is in *pisces* and *aries* about the time of her first quarter, and rises about noon: but her rising is not then taken notice of, because the sun is above the horizon.

In spring, the moon is in *pisces* and *aries* about the time of her change; and as she then gives no light, her rising cannot be perceived.

In summer, the moon is in *pisces* and *aries* about her third quarter; and then, as she rises not till about midnight, her rising passes unobserved, especially, as she is so much on the decrease.

In autumn, *pisces* and *aries* are opposite to the sun; and therefore, the moon is then full in them, and rises immediately after sun-set for several evenings together; which makes her rising very conspicuous, as it is so beneficial to the farmers, in affording them an immediate supply of light after the going down of the sun, for reaping the fruits of the earth.

LECTURE XII.

On ASTRONOMY.

ALL the planets and satellites are enlightened by the sun, and cast shadows toward that part of the heaven which is opposite to the sun as seen from them.

If the sun and earth were equally big, the earth's shadow would be infinitely extended; and always of the same bulk, and would do more than cover the planet Mars when opposite to the sun, because Mars is much less than the earth.

If the earth were bigger than the sun (and to us it seems to be the biggest body in the universe) its shadow would still be the bigger the farther it extended; and would even cover Jupiter and all his moons, when Jupiter is opposite to the sun.

If the sun be bigger than the earth, the shadow will be of a conical figure; and end in a point at a certain distance from the earth.

But the earth's shadow never reaches Mars, although that planet, when opposite to the sun, is not above 42 millions of miles from the earth; which demonstrates, that the sun is much bigger than the earth.

The moon is eclipsed, when she falls into the earth's shadow. Therefore, she can never be eclipsed but at the time of her full; because, that is the only time of her being opposite to the sun. If she were a luminous body, she could not be darkened by the earth's shadow. For, a candle will suffer no diminution of its light, by being placed in the shadow of a board, or globe, enlightened on the opposite side by another candle.

The sun is said to be eclipsed, when the moon passes directly between him and any part of the earth; which can only be at the time of new moon. But, although the moon may then hide the sun from part of the earth, and *that* part must be darkened, because the moon's shadow covers it; yet, as she does not take so much as a single ray of light from the sun, the sun, strictly speaking, is never eclipsed by the moon; any more than by the convexity of the earth, when it hides him from our sight. Notwithstanding, when the moon hides the sun, or any part of him, from our sight, we say, the sun is eclipsed.

If the moon's orbit lay in the * plane of the ecliptic (in which the earth always moves) the sun would be eclipsed at the time of every new moon; and the moon would be eclipsed at the time of every full.

But one half of the moon's orbit is on the north side of the plane of the ecliptic, and the other half on the south side of it. Therefore, the moon's orbit cuts the plane of the ecliptic only in two opposite points, which are called *the moon's nodes*. The angle of the moon's orbit with the ecliptic is 5 degrees 18 minutes.

* If a circle be drawn on a piece of smooth flat paper, the paper may be justly called the plane of that circle.

When the moon is any thing more than 12 degrees from either of her nodes at the time of being full, she passeth clear of the earth's shadow; and therefore she cannot be eclipsed at that time. But when she is within 12 degrees of either node at full, she is eclipsed; and if she be in either of the nodes, the eclipse will be central.

When the moon is any thing more than 18 degrees from either of her nodes at the time of change, she either passeth above or below the sun; and therefore the sun cannot be eclipsed at that time. But when she is within 18 degrees of the node at the time of change, she eclipseth the sun to some part of the earth. And if she be in the node, the eclipse will be central to that point of the earth's surface which is in a right line between the sun's center and the earth's.

If the moon's nodes kept always in the same signs of the ecliptic; in whatever signs the sun and moon were eclipsed in any given year, they would be so in every year after.—But the eclipses fall back every year, from the consequent towards the antecedent signs, in such a manner as to prove that the moon's nodes move backward $19\frac{1}{3}$ degrees every year: and therefore, in 18 years 225 days, they move backward through all the signs and degrees of the ecliptic.

From the time of the sun's being in conjunction with either of the moon's nodes, to the time of his being in conjunction with the other, is 173 days. If the nodes had no motion, the interval between these conjunctions would be $182\frac{1}{2}$ days, or half a year.

In 18 years 11 days 7 hours 43 minutes, there is a conjunction of both sun and moon with the same node. And therefore, in that time, there is a period or restitution of the same eclipses.

The darkness at our SAVIOUR's crucifixion could not possibly be occasioned by a natural or regular eclipse of the sun ; for it was at the time of the passover, which was always kept at the time of full moon.

He was crucified on the day next before the Jewish sabbath, which being kept on our Saturday, the Crucifixion was on Friday. So that the passover full moon in that year was on a Friday.

But it appears by calculation, that there was only one passover full moon on a Friday from the 20th to the 40th year of our Saviour ; and *that* particular full moon was on the third day of April, in the 33d year of his age, accounted from the vulgar æra of his birth.

The 33d year of Christ was the 4746th year of the *Julian* period, and the fourth year of the 402d *Olympiad*.

Pblegon, a heathen writer, tells us, that in the fourth year of the 402d *Olympiad*, there was the greatest eclipse of the sun that ever was known ; and that “ *it was night at the sixth hour of the day.*”

Ptolemy's canon fixes the year, in which the commandment was given to *Ezra* by *Artaxerxes Longimanus*, to restore the state of the Jews, to the year of the *Julian* 4256 : and, according to *Daniel's* prophecies, the death of CHRIST was to be at the end of 70 annual weeks, or 490 years, after that time.

And 490 years being added to 4256, makes 4746 ; the above year of the *Julian* period, which we prove astronomically to have been the prophetic year of our Saviour's death ; concerning which, we have the testimony of a heathen writer, who, being not an astronomer, mistook a supernatural darkness for an eclipse of the sun.